



Advantages of a Modular Mars Surface Habitat Approach

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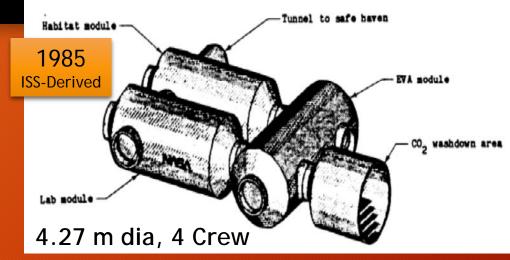
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Mars Surface Habitat Evolution









Monolithic vs. Modular Habitats



Monolithic
Single, Large
Habitat

VS.

Modular

Multiple, Small

Habitats



■ Monolithic

- Works well for a single visit to one site (Apollo-style missions)
- Crew has everything they need without leaving the lander
- Size limited by Earth launch vehicle payload shroud + lander payload constraints

■ Modular

- Works well for repeat visits to the same site
- Smaller → more vehicle options for Earth launch or Mars lander
- Have to configure multiple elements on Mars

Two Important Considerations



- Post-landing crew recovery period
 - After long microgravity transit, crews may need physical recovery period before "Mars-walk" medical clearance
 - Strength + neurovestibular recovery

Whatever crew lands in may have to carry everything they need for a few days



- Single vs. multiple visits to the same landing site
 - If first crew lands in monolithic habitat...what do subsequent crews to the same site land in?
 - Leave habitat on lander or off-load it?
 - Multi-expedition habitat must be more robust than one-time use habitat
 - Can we use empty logistics containers as habitable modules?

Single vs. multiple visits to a given site have different optimal architectures

Surface Systems Approach 2018 Mars Study Capability (MSC) Team

- Established surface system functional requirements within the integrated mission architecture
- Identified needed cargo elements
 - Emphasized commonality to eliminate unique elements
- Developed operational concept details
 - Which pieces need to arrive on which lander?
 - How do we unload and assemble everything?
- Established manifesting "rules" to better compare concepts
- Tried to minimize unique elements
 - Similar shell for Logistics, Descent, and Airlock Modules
 - Common mobility chassis, with pressurized, unpressurized or robotic rover outfitting

2018 Basis of Comparison Architecture Mars Study Capability (MSC) Team



- Retained Evolvable Mars Campaign's (EMC) "Field Station"
 - Multiple missions to a single landing site



- 22 t payload capacity Mars landers
 - 3-3-2 lander cadence



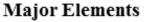
- Low-energy, hybrid in-space transit architecture
 - Longer in-space transit decreases surface stay to ~300 days per expedition
 - 5 sol Mars Ascent Vehicle rendezvous point



- Modular surface habitation
 - Four-hatch Airlock Module serves as the cornerstone
 - Crews land in a Logistics Module-sized Descent Module, which then becomes a habitable surface module

Requires fewer landers relative to the EMC concept, with lower landed mass over 3 expeditions than most previous schemes

Notional Mars Surface Mission Elements



(Dedicated Lander)



Mars Ascent Vehicle (MAV)

Stowed Elements (In Another Element)



Crew



EVA Suit + Primary Life Support



Launch/Entry Suits



Maintenance, Logistics & Consumables

Supporting Elements (Deck Mounted)

Power Management

& Distribution

Rover Descent Logistics Cabin Module Module

MODULAR HABITATION



Mobility Chassis



Kilopower Unit



Unpressurized Rover



Airlock

Module

Rover



Pressurized



Crew Support Rover

Off-loading Hoist





Atmospheric ISRU

Tunnel

General Concept of Operations

Conceptual Mission Series to a Single Exploration Site

FIRST Predeploy cargo THEN Ascent
Vehicle and ISRU

WHEN tanks are full, 1st crew lands

subsequent crews add modules





Power System + Hab Module + Cargo



Ascent Vehicle + Propellant Manufacturing





Hab Modules + Crew + Cargo







Rover Cabin



Descent Module MODULAR HABITATION

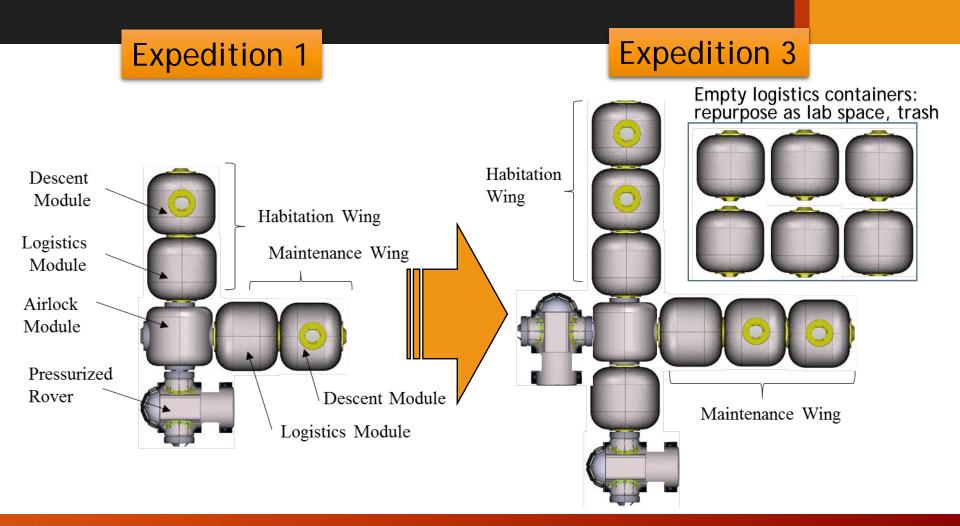


Habitable Logistics Module



Airlock Module

Field Station Build-up



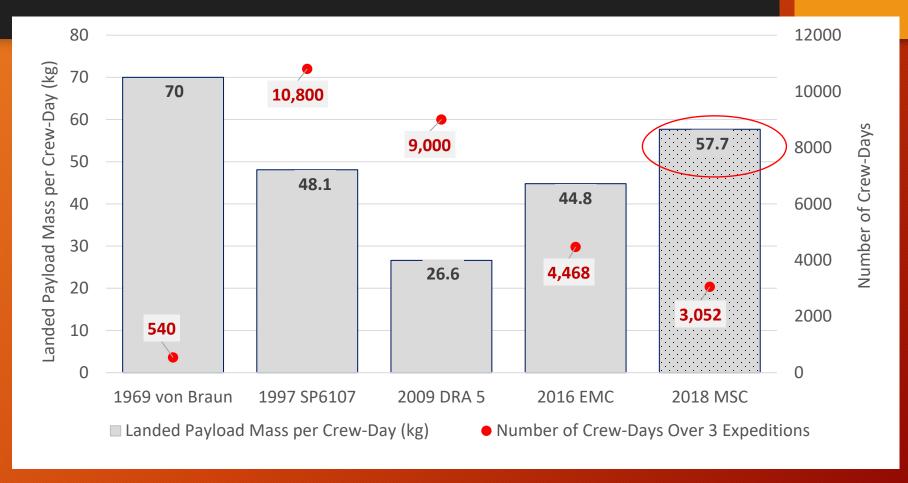
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	Mission Concept				
	1969	1997	2009	2016	2018
	Von	SP 6107	DRA 5	EMC	MSC
	Braun				
Number of Landers	3	8	6	10	8
Expedition 1	1	4	2	4	3
Expedition 2	1	2	2	3	3
Expedition 3	1	2	2	3	2
Payload Capacity per Lander (t)	12.68	65	40	20	22
3-Expedition Cumulative Landed					
Mass (t)	38.04	520	240	200	176
= (#landers) x (payload/lander)					

If landed mass is the metric of choice, MSC concept looks pretty good

Landed Payload Mass Per Crew Day Cumulative Over 3 Expeditions

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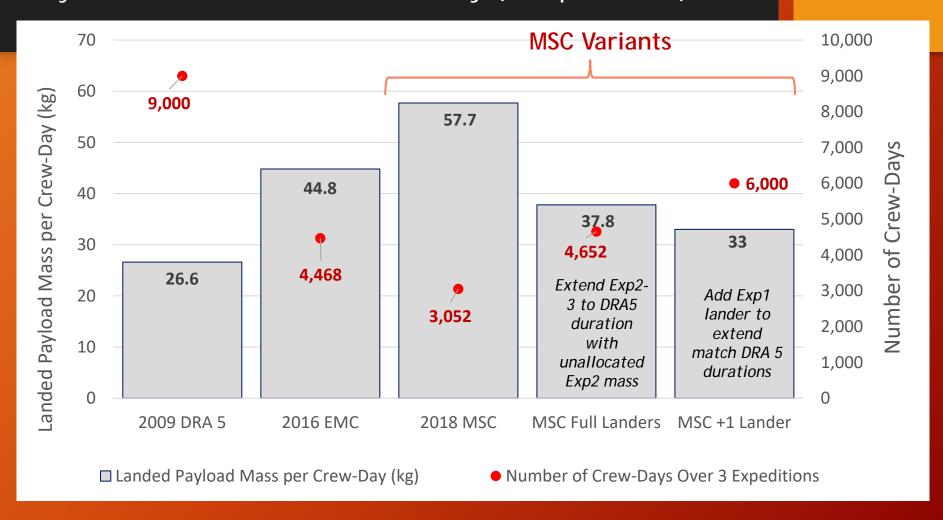
If landed mass per crew day is metric of choice, MSC compares poorly

Why so much variation?

- 1. Multi-module structure is less mass-efficient
 - At current design fidelities, difficult to gauge by how much
- 2. Mass estimates increase as concepts/models are refined
 - Pressurized rover grew from 4.8 to >6 t from 2009 to 2018
 - Monolithic Habitat grew from 16.5 to 19.3 t
- 3. Maintenance models are based on number of pressurized modules, not pressurized volume
 - Baked-in disadvantage for modular architecture
- 4. Surface stay duration is key
 - Infrastructure—not consumables mass—is the driver

Longer Stay
Payload Landed Mass Per Crew Day (3 Expeditions)

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Advantages of a Modular Habitat Approach

1. Smaller habitats fit on a smaller landers

- Eliminates a key lander size-driver → less cost/risk
- More Earth launch system options
- More commercial/international partner opportunities

2. Reduced Risk

- A damaged module could be isolated and replaced
- Smaller hab designed to be relocated is more tolerant of offcourse landing
 - Off-course landing → loss of mission for monolithic hab

3. Solves the "subsequent crew problem"

- Monolithic: either keep sending big habs, or design another element for subsequent crews to land in → costly
- Modular: each crew lands in the same type of element, which is added to the field station as habitable volume

Advantages of a Modular Habitat Approach

4. Improved Habitability

- Can separate clean/quiet area from dirty/noisy work space
- Pressurized volume increases over multiple expeditions
 - Or can replace worn-out modules as new modules arrive
- Retired modules can be dedicated for trash management
- More accessible than climbing up/down lander to a MonoHab

5. More Flexibility

- Can improve/add new tech to later Expedition modules
- Smaller modules are easier to build, transport and test on Earth
 - Easier for small/new providers to participate

6. Lower cumulative mass compared to previous studies

- >30% savings vs. DRA 5.0 architecture
- Could be optimized with longer surface stays

Disadvantages of a Modular Habitat Approach

- 1. Operationally less efficient
 - Have to offload, transport, assemble modules on Mars
 - Have to connect distributed services similar to ISS
- 2. Larger footprint on Mars
 - May require surface preparation
- 3. Higher Handling Damage Risk (on Mars)
 - Offloading/transporting/assembling modules
- 4. Potentially less commonality with transit habitat
- 5. Adds complexity to Logistics Module
 - Off-set by improved commonality
- 6. More complicated lander packaging/balancing



Key Take-Aways Modular vs. Monolithic Habitats

- ☐ Modular habitats work well for repeat visits to one site
 - Monolithic habitats may work better for one-time visits
- Modular habitats offer:
 - ✓ Risk reduction

- ✓ Increased launch/landing system options
- ✓ Operational flexibility
- ✓ Lower cumulative landed mass
- ☐ Landed mass doesn't tell the whole story
 - Normalized mass per crew-day doesn't either
 - Comparing to earlier references requires updating the earlier works for current usage models and element concepts
- ☐ If landed mass is the metric of choice, best "value" is to maximize Mars surface stay
 - Regardless of habitat type

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Questions?

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